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Thermal Performance of Naturally Ventilated Classroom in the Faculty of Engineering Hasanuddin University, Gowa Campus

M. T. Ishak[1], B. Hamzah[1*)], Z. Gou[2], R. Rahim[1], and S. Latif[1,3]

[1]Department of Architecture, Hasanuddin University, Makassar Indonesia 90245
[2]Griffith School of Environment, Griffith University, Quensland Australia 4222
[3]Department of Architecture, University of Muhammadiyah, Makassar Indonesia90221
Emails: taufikishak60@yahoo.com; *)baharsyah@unhas.ac.id (corresponding author); z.gou@griffith.edu.au; yb8bri@yahoo.com; and sahabuddinlatif@gmail.com

ABSTRACT

This study aims to identify the thermal performance of naturally ventilated classrooms of the new campus of Faculty of Engineering, Hasanuddin University in Gowa. The natural ventilation system has three main functions that are to provide healthy air for occupants, to provide thermal comfort to the occupants, and to cool the fabrics in the building interior. Thermal comfort perceived by the user is determined by many factors, including physical, psychological, etc. This research was conducted by using the experimental method with research analysis using CFD (Computational Fluid Dynamics) simulation method. The input parameters in the simulation were obtained through field measurement in the form of room dimension, ventilation open area, and microclimate parameter. The simulation is carried out at maximum open conditions in existing ventilation system with open and closed class door treatment. The simulation treatment of airflow input speeds were 0.25, 0.5, 0.75, and 1 m/s. The results showed that the existing ventilation system of Classroom at Faculty of Engineering (FoE) Hasanuddin University (Unhas) with an opening ratio of 16.59 to 22.76% of the floor area is good enough to flow and distribute comfortable air movement inside the classroom, especially at airflow speeds above 0.5 m/s.

Keywords: natural ventilation, classroom building, tropic, air temperature, airflow

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1. INTRODUCTION

The room ventilation system has three main functions: (1) ensuring an indoor air change, (2) giving comfort to the room users, and (3) cooling the materials and furniture in the room. Proper ventilation systems are needed to achieve thermal comfort conditions in classrooms buildings. For energy efficiency, the use of a natural ventilation system is highly recommended. But if this natural system can no longer satisfy the user's convenience, then an energy-efficient mechanical ventilation system can be used instead. Therefore the design of ventilation system, both natural and mechanical is a significant aspect of making energy efficient and comfortable buildings.

Climate is one of the factors that influence the design of the building. One of the climate impacts considered to be detrimental to humid tropical regions such as Indonesia is the heat that enters through the outer walls and fenestrations of buildings. The magnitude of the heat propagation and the high humidity and the low movement of the wind cause increased the temperature inside the building. The higher the degree of heat that enters the building, the higher the cooling loads of the air conditioning device. Large cooling loads indeed require a significant electrical energy as well.

According to Karyono [1], an essential strategy for building design allows for conventional heat transfer takes place by creating openings such as windows, which would enable cross-air ventilation to occur optimally. The strategy of cooling space and buildings with air drainage in humid tropical regions as an effort to exploit the positive potential of climate is very beneficial in energy saving has been done by several researchers [1], [2], [3].

Thermal comfort is one of the requirements for the users that enable them to work well and more productively. Sensharma, Woods, and Goodwin [4] found that there was a positive correlation between room environment and the productivities of workers in the office building. This thermal comfort is not just requirement for office buildings but also for educational buildings. A quite old study back in 1968 revealed that there was a positive effect of the thermal quality of classrooms on students' performances [5]. An extensive literature review by Mendell and Heath [6] showed a good correlation between indoor school environments and the performance and attendance of children.

Liping and Hien [7] argue that increasing the speed of indoor airflow can increase the range of the thermal comfort zone, especially for natural ventilation systems. According to Gratia et al. [8], entering air with natural ventilation can be relied upon to improve thermal comfort in the interior of the building. Based on the survey conducted in 2012, Baharuddin et al. [9] concluded that the classrooms in the Classroom Building of Faculty of Engineering, Hasanuddin University of Gowa, have not met the thermal comfort standard due to the high air temperature and the absence of airflow in the building interior. Later on, Latif et al. [10] have conducted a research to study the airflow performance at the Classroom Building of Hasanuddin University Faculty of Engineering in Gowa, to find an airflow strategy that can accelerate the process of heat dissipation. This experimental study used the CFD (Computational Fluid Dynamics) simulation method. It was concluded that adding the open exposure ratio to 21.60%, with the details of the inlet openings (14.50%) and the outlet openings (7.10%), and proper exposure of openings optimized air circulation.

This study is a preliminary study to analyze the thermal performance of the existing condition of the natural ventilation system at the Classroom Building in the Faculty of

Engineering, Hasanuddin University Gowa campus, which in turn will be used to improve the ventilation system in an effort to increase thermal comfort naturally.

2. LITERATURE REVIEW

A. Natural Ventilation System

Natural ventilation is a passive cooling technique to maintain a good level of air quality that is achieved in a natural way. In some cases, buildings require a larger air circulation to compensate for indoor air temperature and high humidity to meet the fresh air-coming needs [11]. Liping and Hien [7] analyzed the use of natural ventilation in buildings located in hot and humid Singapore. This study analyzes the natural ventilation strategy and has proven that a full day of natural ventilation can improve thermal comfort in humid tropical climates. The researchers observed four different ventilation strategies and materials in the building envelope, using the TAS (Thermal Analysis Software) program. They analyzed the night ventilation strategy, day ventilation strategy, full ventilation strategy and no ventilation at all. The authors concluded that the 24% of window opening ratio to the wall is ideal for achieving the best thermal comfort conditions in buildings. Horizontal shading devices are recommended for all facades in order to improve thermal comfort.

Gratia et al. [8] concluded that air infiltration with natural ventilation systems can be used to improve thermal comfort in indoor spaces, but the efficiency of these systems depends on climatic conditions, so some strategies for reducing internal heat may be required under certain conditions. The successful design of a naturally ventilated building requires a good understanding of the airflow pattern and the effects of surrounding buildings. The goal is to get enough clean air circulation in all parts of the space in the building. The fulfillment of this goal depends on the location of windows, interior design and wind characteristics [11].

The main factors affecting the airflow pattern entering the building are the size and shape of the inlet hole, the opening location, the type and configuration of the inlet including the configuration of other adjacent elements such as internal partition, projection, and vegetation.

a. The shape and size of openings

Cherian [12] has undertaken a thorough investigation of the building's natural ventilation in a warm-humid climate. Average internal air velocity expression as a percentage of external wind speed. According to Chenvidyakarn [13], the size and shape of openings is an important factor that determines the flow of air within the building. For buildings with opposite wall openings, the indoor wind speed may increase if the wind direction forms an angle to the inlet. Larger airflow levels can also be achieved when the outlet is larger than the inlet openings. On the contrary, the air velocity is more evenly distributed throughout the space when the outlet is smaller than the inlet; this is because the kinetic energy of the wind is converted to a static pressure around the bottom of the opening [14].

The shape and configuration of openings also have an effect on the internal airflow speed. Horizontal opening or square inlet openings are better than the vertical ones. The horizontal inlet provides optimal performance when the angle of wind arrival is directed at a position of about 45° Figure 2.

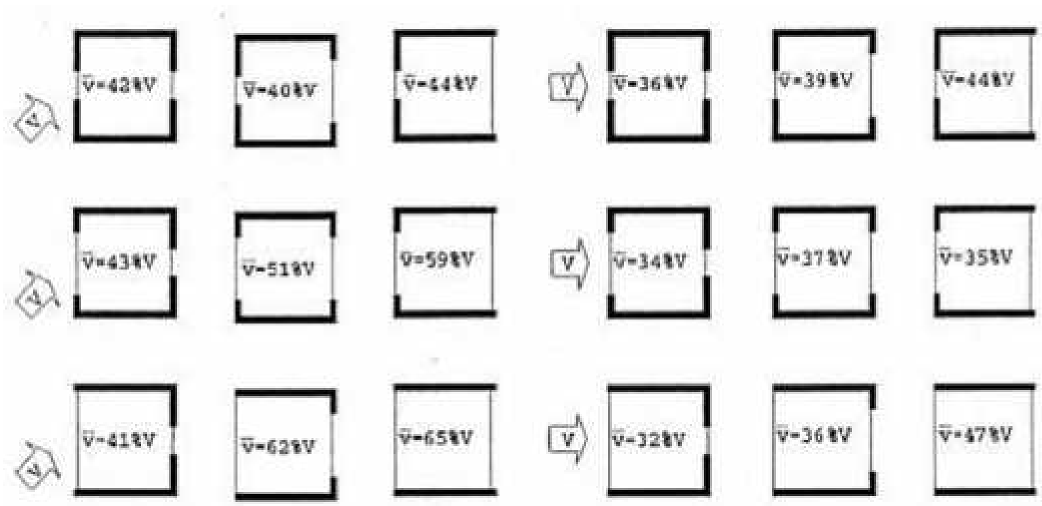

Fig. 1. Average percentage of internal, external velocity as a function of wind direction and inlet/outlet ratio [14]

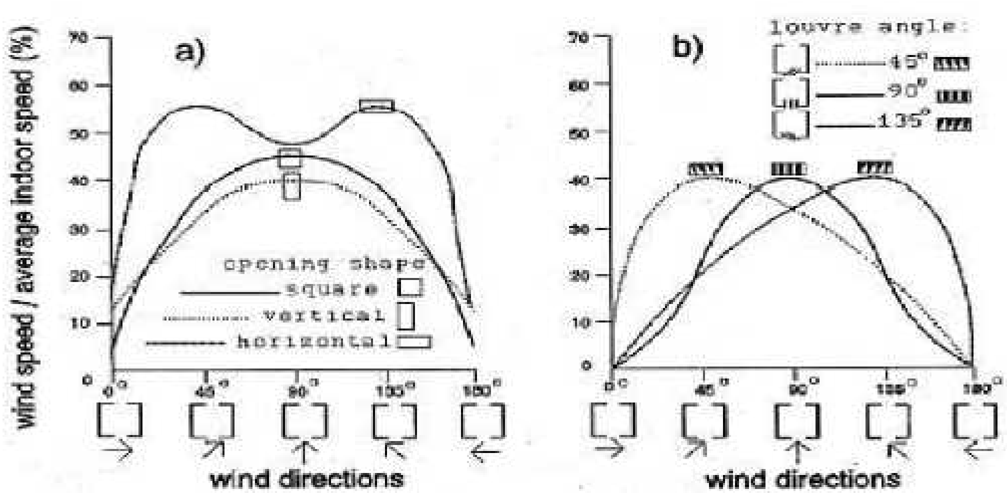

Fig. 2. The impact of wind direction based on the opening shape and the louvre angle [14]

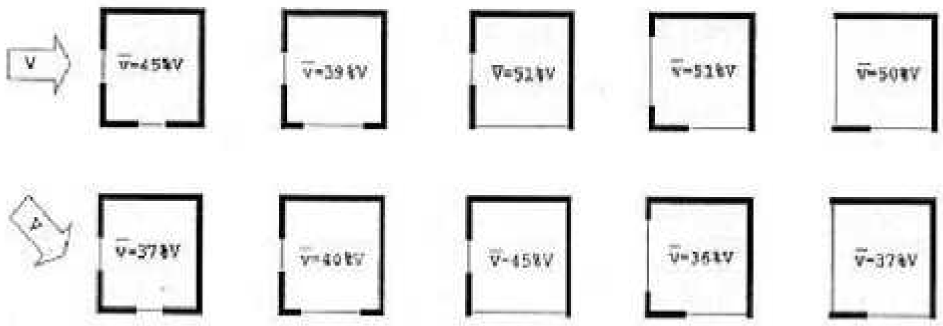

Fig. 3. Effect of proximity of openings and size of the walls [13], [14]

b. Opening Location

The optimal indoor cross-ventilation occurs if the openings on three different facades. However, this configuration is uncommon. For rooms with openings on two adjacent sides, higher mean air velocities can be achieved when the wind angles are perpendicular to the inlet (see Figure 3) [13], [14].

In buildings with central openings such as lobby and voids, the internal air distribution is largely determined by the total area of openings on the wall [15]. Lechner [15] and van den Engel and Kemperman [16] argue that, if natural ventilation is not functioning optimally for excess heat exhaust including heat sinks, it is advisable to use mechanical devices.

B. Thermal comfort study in Indonesia

Thermal comfort is defined in the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 55 standard as the “that condition of mind which expresses satisfaction with the thermal environment” [17]. This definition is later adopted by International Standard Organization (ISO) in its Standard 7730 [18]. That is a state of mind that expresses the satisfaction of environmental thermal conditions. Thermal comfort research in humid tropical buildings was conducted in Indonesia first between 1936 and 1940 by Mom and Wiesebron [19]. Some research on thermal comfort has been done in Jakarta [20]. This research is focused on the office building. In addition, studies involving objective measurements and thermal comfort surveys on a wider scale have been conducted in Yogyakarta [21]. This study focused on naturally ventilated housing.

Recent studies in Indonesia carried out by Hamzah et al. [22], [23] and Karyono et al. [24] were focused on the university and secondary schools classrooms. Hamzah, et al. [22], [23] investigated the naturally ventilated classrooms, while Karyono et al. [24] studied the air conditioning classrooms. Hamzah et al. [22] found that the thermal condition of the classrooms did not meet the requirement of

ASHRAE 55 [17] and SNI standard 03-6572-2001 [25]. The major finding of this study is that more than 80% voted the central position (−1 to +1), either in ASHRAE or Bedford scale and the neutral temperature about 29.6 °C. Hamzah et al. [23] found similar thermal sensation and preference of secondary school students in the naturally ventilated classrooms. Despite the hot temperature, most of the students felt comfortable. More than 85% of students voted the central options (-1 to +1). Karyono et al. [24] found that comfort temperature was 24.1 °C Ta and 24.9 °C Ta for students at Universitas Tarumanegara (Untar) and Universitas Mercu Buana (UMB), respectively. Both figures are very low in comparison to the naturally ventilated classroom in the study carried out by Hamzah et al. [22] and [23].

C. Thermal Comfort Zone in Indonesia

Mom and Wiesebromn cited in Soegijanto [19], proposed thermal comfort zones for Indonesians' people which are vary: Comfortably cool at 20,5 °C-22,8 °C (T_e); Comfortable (optimum) at 22.8 °C-25,8 °C (T_e); Comfortably warm at 25,8 °C-27,1 °C (T_e). This proposed thermal comfort zone later on adopted by the government to be the requirement in the national standard SNI 03-6572-2001 [25].

The guideline uses the effective temperature (Te), which is defined as the temperature of a stagnant and saturated atmosphere, which would, in the absence of radiation, produce the same effect as the atmosphere in an inquiry. Therefore, it combines the effect of dry air temperature and humidity [26]. Effective temperature (T_e) is defined as the temperature at 50% of relative humidity. According to Satwiko [27] thermal comfort of humid tropics can be achieved with limits of 24 °C <T <26 °C, 40% <RH <60%, 0.6 <V <1.5 m/s, leisure activities, light clothing and coating.

D. Computational Fluid Dynamics (CFD)

CFD is an approach of mathematical equations using the Navier-Stokes equation which is the law which refers to the conservation of mass, momentum and energy conservation as the basis of fluid analysis [28] [29].

The continuity equation:

$$\frac{\partial}{\partial} + \Delta.(\rho \quad) = 0 \qquad (1)$$

The momentum equation:

$$\rho \frac{DV}{D} = \Delta.\tau_{i} - \nabla p + \rho F \qquad (2)$$

Equation of energy conservation:

$$\rho\, De/D + p(\nabla.V) = \partial \quad /\partial - \nabla.q + \Phi \qquad (3)$$

where ρ is the fluid density, V is the fluid velocity vector, τ_{ij} is the viscous stress tensor, p is pressure, F is the body forces, e is the internal energy, Q is the heat source term, t is time, Φ is the dissipation term, and ∇.q is the heat loss by conduction.

Heat radiation transfer occurs between solid objects and ambient environmental conditions or between two solids in the absence of an intermediate medium. This is the only type of heat transfer that occurs in a vacuum. Heat flows by electromagnetic radiation [30]. Any object with a temperature of 0ºK (-273ºC) emits radiation proportional to its four surface temperature, the law of Stefan-Boltzmann [31] [32]:

$$q = \varepsilon \; A \; {}_{s}^{4} \qquad (4)$$

where q is the surface radiation emission (watts / m2); ε surface emissivity, value 1 for black body radiation, while for other natural objects about 0.9-1.0; σ is the Stefan-Boltzmann constant 5.67x10-8 w / m2; T_s is the surface temperature (ºK); A is surface area.

To measure the magnitude of the surface radiation of solids, to the environment can be with the equation below.

$$q = \varepsilon \; A(T_s^4 - T_l^4 \qquad (5)$$

Where T_s is the surface temperature of the object (ºK); T_l is the ambient temperature.

3. THE STUDY METHOD

This study was using an experimental method by applying CFD (Computational Fluid Dynamics) SolidWorks 2016 software as a simulation tool. The SolidWorks CAD program integrates with SolidWorks Flow Simulation in SolidWorks CAD program so that the process of defining the material, domain set, boundary condition, meshing to output can all be done in one single software [30] [33].

Several steps were carried out to perform the simulation as follows: The first step was to make the geometry of classroom. The classroom model/geometry is made up of two types, then defines the physical material and fluid material properties to be simulated, then determines the boundary conditions and set goals. Furthermore, the meshing process will be done by software automatically at the iteration stage.

The input parameters in the simulation were obtained through field measurement in the form of lecture dimension, ventilation open area, and microclimate parameter. Input parameters for macroclimatic conditions were taken from environmental climate data on Saturday 16 April 2016, obtained from Vaisala environmental station located at the roof-top of Architecture Building, Faculty of Engineering, Hasanuddin University, Gowa campus. These microclimate data measurements and macroclimatic data were used as airflow simulation input parameters.

The CFD simulation is performed to determine the airflow distribution and its effect on the temperature conditions in the classroom. The simulation performed on each type of lecture room is 8 times with details of four times the simulation of closed room door position and 4 times the position of open room door, with the treatment of wind input speed respectively 0.25, 0.5, 0.75, and 1 m/s.

The results of the simulation were air velocity and air temperature distribution inside the classroom. The air temperature distribution and airflow velocity are shown in the form of contour, which was adjusted to the size of the room, the position of the openings.

4. RESULT AND DISCUSSION

A. Macro Climate Measurement Results

Survey of climate data was taken on 16 April 2016. In general, the weather condition on that day was mostly sunny with clear sky. Environmental climate data on that day was obtained from Vaisala equipment, which is located at the Architecture Building, Faculty of Engineering, Hasanuddin University Gowa Campus.

The weather conditions at the time of measurement can be seen in Figure 4, that on the day of measuring the outside air temperature from 06.00 to 18.00 CIT (Central Indonesia Time), ranging from 26.5 ºC to 32.5 ºC, with an average of 30.27 ºC. Relative humidity ranges from 46.07 to 76.58%, with an average of 61.33%. This indicates that the measurement is done on a hot day.

B. Result of Simulation of Existing Classroom

a. Type-1 Classroom

The Type-1 classroom is a room with 9 m wide, 10.8 m long and 3.2 m of ceiling high. Figure 5 shows openings in Type-1 Classroom with closed and open doors. The classroom is equipped with six openable windows, three fixed windows, and 20 bovenlicht windows. All openable windows and bovenlicht windows were maximumly open. The floor area is 97.2 m^2. In the case of the door closed, the open area is 16.59% (inlet 11.54% and outlet 5.04%). If the door is open, the open area becoming 19.99% (inlet 11.54% and outlet 8.45%).

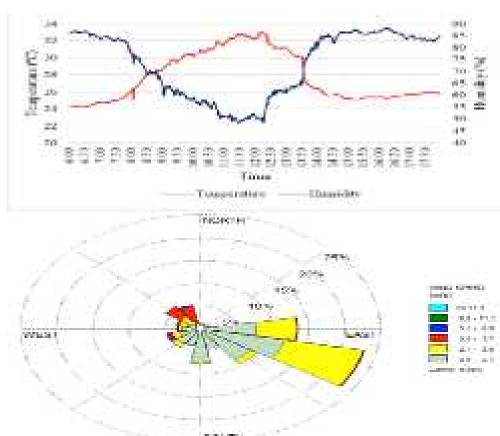

Fig. 4. The outdoor air temperature and relative humidity (top), and the windrose of wind velocity and wind direction recorded by Vaisala on 16 April 2016 from 8:00am to 6:00pm.

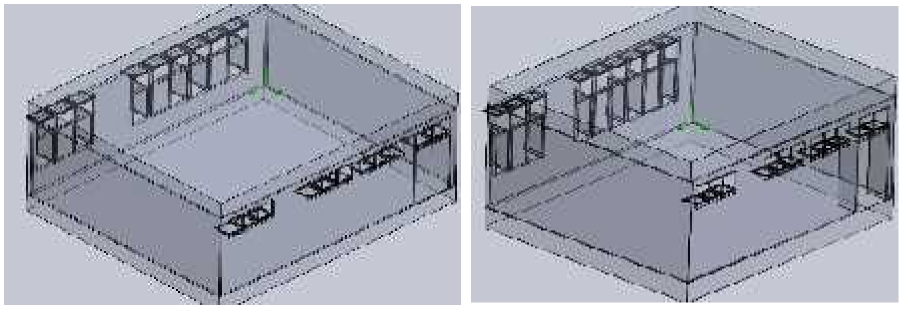

Fig. 5. The geometry of Type-1 Classroom: door closed (left) and door open (right)

Figures 6 and 7 show the results of the existing simulation of Type-1 Classroom with the closed and open door, respectively. The distribution of air velocity and indoor temperature are shown the horizontal contour at Y = 1.1 m and vertical contour (Z=3.9 m). Figure 6 shows the simulation results of air velocity distribution and temperature distribution in the Type-1 Classroom with a closed door. As seen in the figure, the room air velocity is good enough in the upper area of the room can drain the usual hot air piled up around the ceiling, but for the effective area used learning activities in the sitting conditions, some spaces especially those far form inlet window, airflow still does not meet the comfortable standards. This is because the airflow velocity distribution is about 0.22 m/s, while the minimum comfortable standard is 0.25 m/s according to Vector Olgay in Lippsmeier [34]. In terms of the temperature distribution, the simulation results show that with the airflow velocity input of 1 m/s, the air temperature in the classroom is slightly cool. The inside air temperature is close to ambient conditions that are only increased by 0.22ºC from the outside temperature of 28.00 ºC

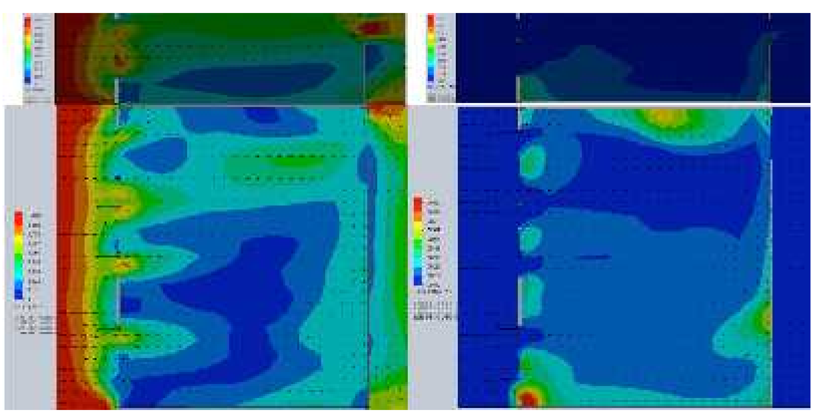

Fig. 6. Distribution of air velocity (left) and the air temperature (right) at Type-1 Classroom with closed door and wind speed input 1 m/s. The vertical contour (Z=3.9 m) at the top and horizontal contour (Y=1.1 m) at the buttom of the figures.

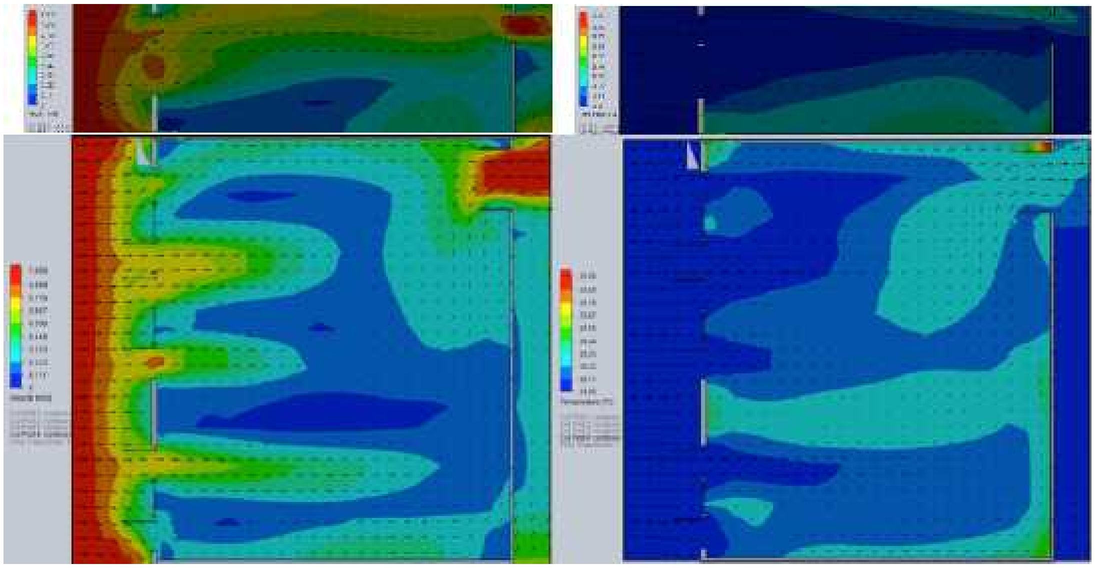

Fig. 7. Distribution of air velocity (left) and the air temperature (right) at Type-1 Classroom with open door and wind speed input 1 m/s. The vertical contour (Z=3.9 m) at the top and horizontal contour (Y=1.1 m) at the buttom of the figures.

Figure 7 shows the simulation results of air velocity distribution and temperature distribution in the Classroom Type-1 with open door. The room air velocity is good enough in the upper area of the room. The air velocity can drain the usual hot air piled up around the ceiling. It can be seen from Figure 7, the highest output air velocity occurs in the door area. This is result in a decreased of static pressure in the area away from the door. This condition decreases the air velocity evenly inside the room. When compared to the closed door, the airflow with open door is still better in indoor airflow velocity but less profitable in its distribution. This is in accordance with research conducted by Latif [33]. In terms of air temperature, the simulation results show that the wind velocity input of 1 m/s can lower the air temperature inside the upper and lower spaces, especially near the door.

b. Type-2 Classrooms

The Type-2 classroom is a room with 9 m wide, 7.2 m long and 3.2 m of ceiling high. Figure 8 shows openings in Type-1 Classroom with closed and open doors. The classroom is equipped with four openable windows, two fixed windows, and 14 bovenlicht windows. All openable windows and bovenlicht windows were maximumly open. The floor area is 64.8m2. In the case of the door closed, the open area is 17.52% (inlet 11,81% and outlet 5.70%). If the door is open, the open area becoming 22.76% (inlet 11,81% and outlet 10.94%).

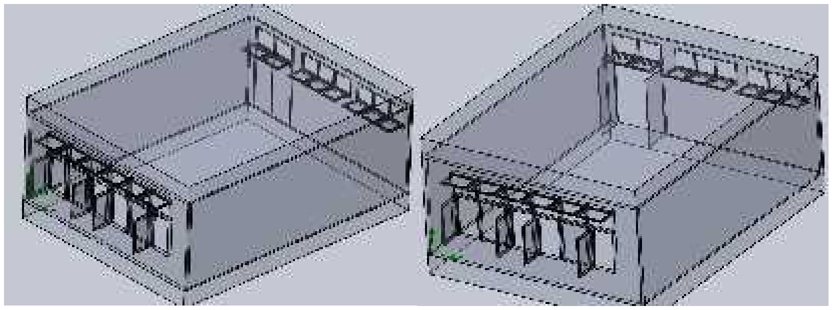

Fig. 8. The geometry of Type-2 Classroom: door closed (left) and door open (right)

Figures 9 and 10 show the results of the existing simulation with closed and open doors in the Type-2 Classroom with the closed and open door, respectively. The distribution of air velocity and indoor temperature are shown in a horizontal contour (Y = 1.1 m) and vertical contour (Z=4.0 m).

Figure 9 shows the simulation result of air velocity distribution and temperature distribution in the Type-2 Classroom with the closed door. The speed of airflow inside the room is good enough that is between 0 - 0.89 m/s. In the upper area of the room it is good to pass the hot air overlaid around the ceiling, but for the effective area used in the learning activities, some space, especially around the space which is not close to the inlet window, airflow still does not meet the standard because the flow rate distribution is about 0 - 0.22 m/s. In terms of the temperature distribution, the simulation results show the wind velocity input of 1 m/s makes the evener distribution of air temperature inside the classroom. The air temperature approaches the ambient condition of 28ºC. This means the airflow inside the Type-2 Classroom with the closed door condition is good enough to flow the hot air.

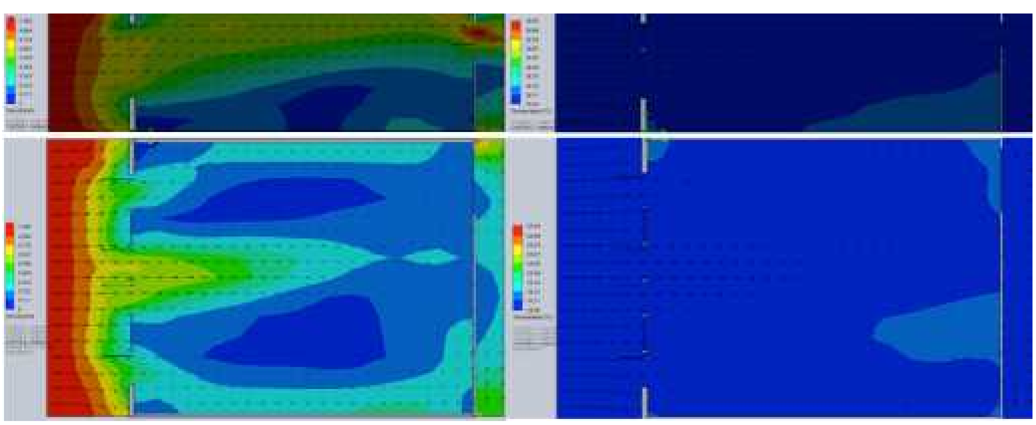

Fig. 9. Distribution of air velocity (left) and the air temperature (right) at Type-2 Classroom with closed door and wind speed input 1 m/s. The vertical contour (Z=4.0 m) at the top and horizontal contour (Y=1.1 m) at the buttom of the figures.

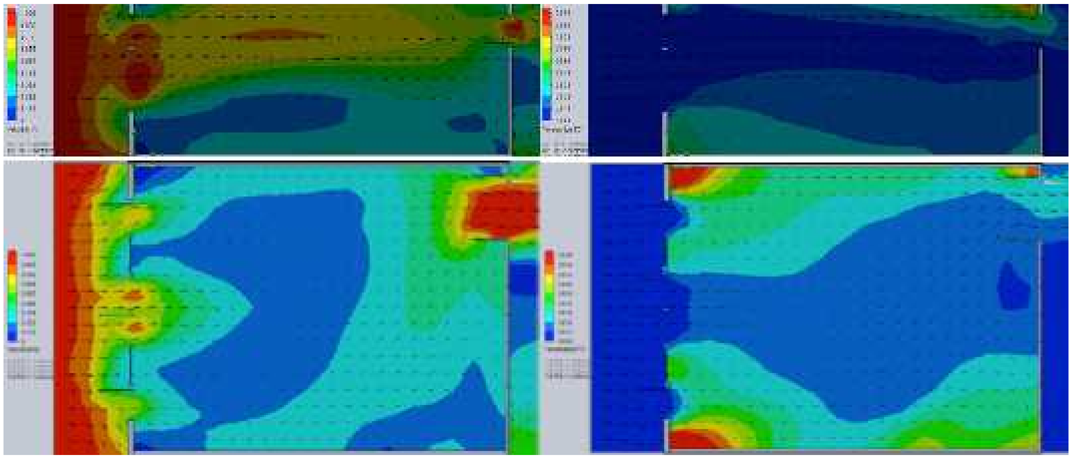

Fig.10. Distribution of air velocity (left) and the air temperature (right) at Type-2 Classroom with open door and wind speed input 1 m/s. The vertical contour (Z=4.0 m) at the top and horizontal contour (Y=1.1 m) at the buttom of the figures.

Figure 10 shows the simulation results of air velocity and temperature distribution in the Type-2 Classroom with the open door. The airflow distribution rate is quite good, between 0.00 - 1.00 m/s. The uneven distribution of airflow velocity in all space is caused by the opening of the door causing uneven static pressure. If the temperature contours are seen, the simulation results show that parts of the temperature are somewhat high and there are parts with the same term as the outdoor climate, due to uneven distribution of airflow.

5. CONCLUSION

The position and extent of natural ventilation openings are critical to air movement within the classroom. The presence of openings on both sides of adjacent walls in the Faculty of Engineering (FoE) Unhas classroom gives a good impact on air movement within the classroom. This is because such opening allows cross ventilation inside the classrooms. The results showed that the existing ventilation system of Classroom at Faculty of Engineering (FoE) Hasanuddin University (Unhas) with an opening ratio of 16.59 to 22.76% of the floor area is good enough to flow and distribute comfortable air movement inside the classroom, especially at airflow speeds above 0.5 m/s. This happens because of the effective cross ventilation caused by the corridor that lies between the classrooms. The simulation with the wind velocity of 1 m/s, showed that the airflow inside the Classroom can reach the speed of 0.78 m/s, with the air temperature ranging from 28.0 to 28.8 °C.

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